HIGHWAYS AND DIRT ROADS AROUND ITIRAPINA AND BROTAS, SÃO PAULO, BRAZIL

FINDINGS AND RECOMMENDATIONS BASED ON A ROAD ECOLOGY EXCURSION OF THE ESCOLA SUPERIOR DE AGRICULTURA LUIZ DE QUIROZ (ESALQ), UNIVERSITY OF SÃO PAULO, PIRACICABA, BRAZIL

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1. INTRODUCTION

An 8 credits (120 hours) road ecology course was taught by Dr. Marcel Huijser and Dr. Katia Ferraz at ESALQ, University of São Paulo, Piracicaba between 29 September 2014 and 24 October 2014. The road ecology course was attended by 14 students. As part of the road ecology course an excursion was organized to the highways and dirt roads near Itirapina and Brotas.

During the field trip the students experienced three different road types:
1. Dirt roads in the Itirapina Ecological Research Station (Estação Ecológica de Itirapina);
2. A two lane road through the Itirapina reserve; and,
3. A 4-lane motorway (SP-225) with mitigation measures (wildlife fencing and wildlife and multi-functional underpasses) between Brotas and Itirapina.

This report is organized based on the findings and recommendations for these three roads.

2. DIRT ROADS IN THE ITIRAPINA ECOLOGICAL RESEARCH STATION

2.1. Introduction

Cerrado vegetation is relatively dense and appears relatively hard to walk through for medium and large mammals. In terrain that is hard to navigate, either because of slope or dense vegetation, wildlife often walk the same path resulting in wildlife trails or game trails. In the Itirapina reserve, there are also a number of dirt roads through the cerrado vegetation (Figure 1). Based on a site visit and the literature it appears that maned wolf may be using the dirt roads as easy travel paths to move through the landscape; it is an easier path than through the natural cerrado vegetation. If wildlife species indeed use dirt roads, then dirt roads influence how wildlife, in this case maned wolf, move through the landscape. Wildlife using dirt roads is not necessarily a problem, but if we know that dirt roads that are designed for humans are having an effect on how wildlife use the landscape, then this knowledge may be used to direct the management of the transportation infrastructure in nature reserves, specifically in relation to the ecological integrity or wilderness character of the ecosystem.

Figure 1: A typical dirt road in the Itirapina Ecological Research Station.

Figure 2: Tracks of a maned wolf on a dirt road in the Itirapina Ecological Research Station.

Figure 3: Close-up of a footprint of a maned wolf on a dirt road in the Itirapina Ecological Research Station.

Another perspective on maned wolves potentially using dirt roads relates to small isolated patches of cerrado surrounded by agricultural lands with unnatural food sources (e.g. orange orchards, chicken farms or dumpsites for dead livestock). Dirt roads may provide for easy access to such unnatural food sources (Figure 4). Removal of or limiting dirt roads may then also make it less likely that maned wolves will use such unnatural food sources and it may reduce human-wildlife conflicts. Of course it remains possible that maned wolf finds these unnatural food sources so attractive that the animals will create wildlife trails leading to and from such unnatural food sources.

As part of the road ecology excursion, the students investigated whether maned wolf is using the dirt roads in the reserve more frequently than could be expected if the maned wolf would not have a preference to walk on dirt roads.

Figure 4: Close-up of a footprint of a maned wolf on a dirt road in the Itirapina Ecological Research Station.

2.2. Preliminary Findings

The Itirapina reserve has many dirt roads and fire breaks throughout the area (Figure 5). The average width of the dirts roads was about 3.3 m (Unpublished data, Bruna G. Oliveira, road ecology student, ESALQ).

Figure 5: Dirt roads and fire breaks (in red) in the Itirapina reserve (Source: Bruna G. Oliveira, road ecology student, ESALQ).

During the field excursion the students recorded where maned wolf tracks entered and left the dirt roads. The average distance that maned wolf followed the road for was 170 m (range 11-820 m; n= 12) (Unpublished data, Bruna G. Oliveira, road ecology student, ESALQ). If an animal travels for more than 3.8 m on a dirt road (based on a 3.3 m width of a dirt road) then it becomes likely that the animal is selecting the dirt road for its movements.

The preliminary data for maned wolf suggest that maned wolf that set foot on a dirt road are indeed selecting dirt roads for their movements. This may also facilitate access to unnatural food sources in the surroundings of the reserve and associated human-wildlife conflicts.

3. TWO LANE ROAD THROUGH ITIRAPINA RESERVE

3.1. Introduction

A two lane road (Rod. Municipal Ayrton Senna) bisects the Itirapina nature reserve and forest plantation (Figure 6). Employees from the Itirapina Ecological Station recorded road-killed animals on this road from April 2012 until September 2014. The staff traveled this road nearly every day between their homes and work.

Figure 6: The two lane road (Rod. Municipal Ayrton Senna) bisects the Itirapina reserve and forest plantations.

As part of the road ecology excursion, the students investigated the distribution of road-killed animals along the two lane road, and an existing bridge (southern stream crossing) and culvert (northern stream crossing) at streams to evaluate their potential as wildlife crossing structures. Furthermore the students explored the options for potential future mitigation measures aimed at reducing wildlife-vehicle collisions and providing safe crossing opportunities for wildlife.

3.2. Findings

3.2.1. Distribution Road-Killed animals

Road-killed animals were mostly located along the section through the forest plantations (Figure 7). The road-killed animals (grouped in reptiles, birds, and mammals) were not particularly concentrated around the two stream crossings (blue and the purple dots). However, capybara (*Hydrochoerus hydrochaeris*) and coypu (*Myocastor coypus*) have been hit by vehicles at or immediately near the creek crossings. One collision with capybara resulted in a human fatality at the northern stream crossing (Figure 8). The data suggest that wildlife-vehicle collisions in general, including with maned wolf (*Chrysocyon brachyurus*), occur throughout the area with forest plantations, but that collisions with semi-aquatic mammals such as capybara occur especially at or near stream crossings. Traffic volume is estimated to be a few thousand vehicles per day, and while the posted speed limit is 80 km/h vehicles often drive around 100 km/h (Pers. Comm. Paulo Ruffino, Itirapina Ecological Research Station (Estação Ecológica de Itirapina)).

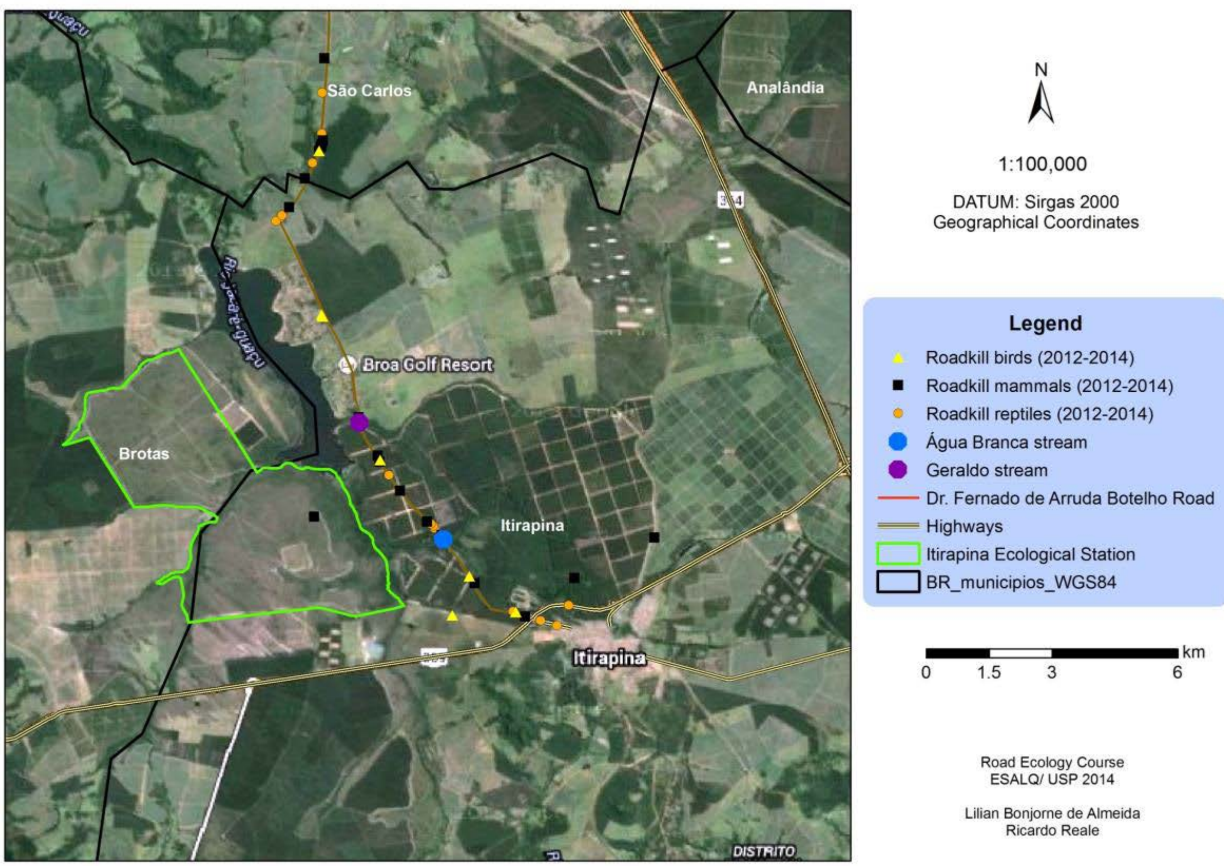

Figure 7: The distribution of road-killed reptiles, birds, and mammals along the two lane road (Rod. Municipal Ayrton Senna) that bisects the Itirapina reserve and forest plantations (Unpublished data. Lilian Bonjorne de Almeida and Ricardo Reale, road ecology students ESALQ).

Figure 8: Cross marking the location of a human fatality as a result of a collision with a capybara (*Hydrochoerus hydrochaeris*), northern stream crossing (Córrego do Geraldo), Itirapina Ecological Station, São Paulo, Brazil.

3.2.2. Potential of Existing Stream Crossings as a Wildlife Crossing

There is one existing bridge (southern stream crossing) and one existing culvert (northern stream crossing) (Figure 6, 9-12). The bridge (southern stream crossing) allows for more or less similar stream characteristics under the bridge as upstream and downstream. However, there is not really suitable habitat for semi-aquatic species, and certainly not for terrestrial species. In addition, the height of the bridge is likely too low for large mammals (Figures 9-11). Furthermore, there is no wildlife fencing that would keep the animals from entering the road and that would guide them towards the structure.

The culvert (northern stream crossing) does not allow for similar stream characteristics in the structure compared to upstream and downstream (Figure 12). The diameter of the culvert is narrower than the stream bed which results in consistently high water velocity throughout the culvert. This is likely to be a barrier to many aquatic species. Furthermore, there is no semi-aquatic or terrestrial habitat inside the culvert at all. Finally, there is a short section of wildlife fencing presumably for capybara, on both sides of the road. (Figure 12-13). However, the fence length is insufficient as is illustrated by the presence of a wildlife trail – presumably from capybara - on the south-east side of the culvert (Figure 13).

Figure 9: Bridge across the southern stream crossing (Córrego água Branca), Itirapina Ecological Reserve, São Paulo, Brazil.

Figure 10: Bridge across the southern stream crossing (Córrego água Branca), Itirapina Ecological Reserve, São Paulo, Brazil.

Figure 11: Bridge across the southern stream crossing (Córrego água Branca), Itirapina Ecological Reserve, São Paulo, Brazil.

Figure 12: Stream culvert (northern stream crossing, Córrego do Geraldo) under two lane road, Itirapina Ecological Station, São Paulo, Brazil. Note the fence that only extends above the retaining wall associated with the culvert.

Figure 13: Wildlife trail (probably mainly used by capybara) at fence end of northern stream crossing (Córrego do Geraldo) leading to the two lane road, Itirapina Ecological Station, São Paulo, Brazil. Note the fence coming in from the left and ending at the tree fern.

3.3. Suggestions for Potential Future Mitigation Measures

The objectives for potential future mitigation measures would most likely be to:

1. Substantially reduce wildlife-vehicle collisions, especially for species that are large enough to be a substantial threat to human safety (e.g. capybara) and species that are considered a conservation concern, at least locally (e.g. maned wolf, brocket deer (*Mazama* spp.).
2. Do not increase the barrier effect of the two lane road for wildlife.

Standard and enhanced wildlife warning signs – similar to the signs that have already been installed at the southern stream crossing (Figure 14) – are often used in an attempt to reduce vehicle speed and/or increase the attention of drivers so that fewer wildlife-vehicle collisions occur. In many cases there is also an attempt to lower vehicle speed in sensitive areas through lowering the posted speed limit and traffic calming measures at selected locations (e.g. speed bumps, radar). However, standard and enhanced wildlife warning signs do not reduce wildlife-vehicle collisions, and traffic calming measures such as speed bumps and radar only result in lower vehicle speeds at those exact locations and not at other location. In addition, traffic calming measures may not be an appropriate measure for through roads to begin with (see e.g. Huijser & Ferraz, 2015).

Figure 14: Wildlife warning sign picturing for maned wolf at the southern stream crossing under two lane road, Itirapina Ecological Station, São Paulo, Brazil.

Measures that are substantially effective at reducing wildlife-vehicle collisions (perhaps at least 80% reduction) include animal detection systems and wildlife fencing in combination with wildlife crossing structures (see Huijser & Ferraz, 2015). Animal detection systems may be implemented as a stand-alone mitigation measure or at gaps in a wildlife fence. Note that medium mammals and smaller species may not be detected by sensors and that most animal detection systems are only able to detect large mammals.

Effective wildlife fencing includes an appropriate design, correct construction practices, and an adequate maintenance program (see e.g. Huijser & Ferraz, 2015). This includes an appropriate height given the target species, appropriate fencing material and posts, a potential overhang on top of the fence to deter species with good climbing abilities, dig barriers to deter species with good digging abilities, appropriate fence length (perhaps at least a few kilometers long), careful construction practices that do not leave any gaps, and regular checks for problems (e.g. gaps in the fence because of falling trees, vehicles that have run off the road, etc.) and prompt repairs.

It is considered good practice to not increase the barrier effect of roads and traffic without providing for safe and effective wildlife crossing opportunities. However, at grade crossing opportunities (e.g. animal detection systems at a gap in the fence), do not serve animal species that may avoid open areas or unnatural substrate. Depending on the design, wildlife underpasses and overpasses can have soil and – especially overpasses- also natural vegetation and provide more natural substrate for species. Existing crossing structures that were installed for other purposes than wildlife (e.g. to allow water to cross under the road), can be modified to allow for wildlife use. Structures can be made suitable for semi-aquatic and terrestrial species in addition to aquatic species. However, the location of such multi-functional crossing structures is often dictated by other factors (e.g. wherever a stream or river crosses a road) rather than where wildlife is most likely to approach and cross the road.

Existing crossing structures for streams and rivers may not be very suitable for wildlife. However, concrete structures typically have a life span of around 75 years after which they need to be replaced. Replacing old structures with structures that not only pass water but that are also better suited for the passage of specific wildlife species is considered good practice. In general it is advisable to design stream and river crossings in a way that preserves the natural stream conditions (see upstream and downstream of the structure for a reference). In addition, sufficient space (width and height) should be available to pass the semi-aquatic and terrestrial target species. Species that are not necessarily associated with streams or rivers may require mitigation measures away from streams and rivers. For example, maned wolves and brocket deer (*Mazama* spp.) are habitat generalists that are unlikely to sufficiently benefit from mitigation measures that are only located at stream crossings.

Specific suggestions for when there is an opportunity to change this stream crossing and associated fencing:

1. Provide a larger structure that is wider than the stream. Ideally the structure is "bottomless" (e.g. a bridge) so that the stream characteristics inside the structure are similar to those upstream and downstream of the structure.

2. Allow for sufficient space in the structure to also provide semi-aquatic and terrestrial habitat (e.g. at least a 2 m wide dry zone) (Huijser & Ferraz, 2015).

3. Make the structure tall enough (e.g. 3-5 m high) to allow for large mammals (e.g. capybara) to cross through the structure (Huijser & Ferraz, 2015).

4. Extend the fencing at least a few hundred meters on both sides of the structure if capybara are the target species (capybara tend to stay close to streams). Habitat generalists such as the maned wolf may require additional structures away from streams and much longer road sections with wildlife fencing (at least several kilometers long) and associated safe crossing opportunities.

5. Design the fence (e.g. height) based on the requirements for the target species. The strength, the jumping, climbing, or digging abilities of the target species should form the basis for the design of an effective fence.

Note that developing good relations between transportation agencies and natural resource management agencies can help implement effective mitigation measures. When the time comes to replace the culvert with another structure, the new structure and associated measures (e.g. wildlife fencing) can be designed appropriately from the earliest planning phases onwards.

4. FOUR-LANE MOTORWAY (SP-225) BETWEEN BROTAS AND ITIRAPINA

4.1. Introduction

The SP 225 highway between Brotas and Itirapina (Figure 15) was upgraded from a two-lane road to a four-lane road in 2006-2007. There are a number of concrete box culverts and culverts for wildlife, livestock, and also a tall bridge across the Rio Jacaré-Pepira, just west of Brotas (Abra, 2012). Some sections have wildlife fencing installed to reduce wildlife-vehicle collisions, especially with large mammals, and to guide wildlife to the safe crossing opportunities.

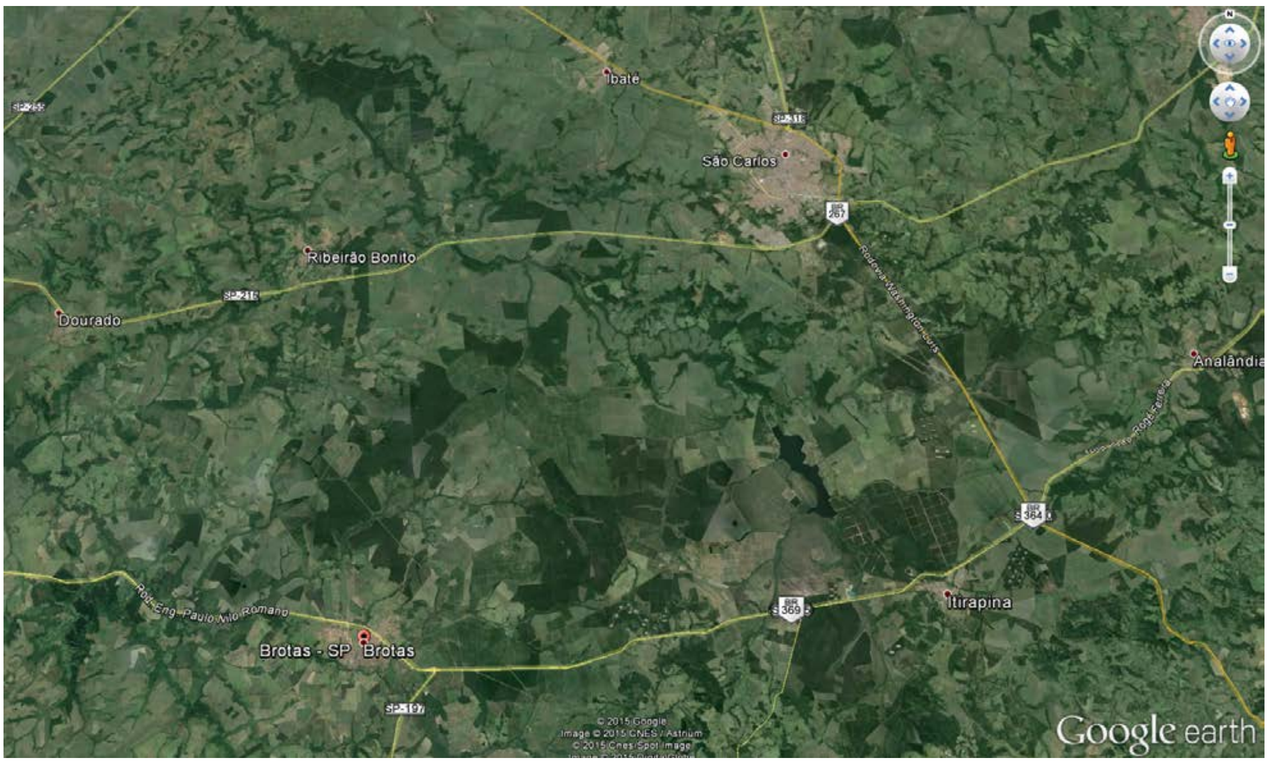

Figure 15: The four-lane motorway between Brotas and Itirapina, São Paulo, Brazil.

4.2. Findings

4.2.1. Wildlife Fencing

The purpose of wildlife fencing is to:

1. Keep wildlife off the highway and, as a consequence, reduce wildlife-vehicle collisions.
2. Funnel wildlife movements to safe crossing opportunities (e.g. wildlife underpasses or overpasses).

Wildlife fencing alone increases the barrier effect of highways and traffic for wildlife. As a general rule, wildlife fencing should never be implemented without also providing for effective crossing opportunities for wildlife (see next section).

It is essential to define the target species before designing wildlife fencing. The climbing, jumping, and digging capabilities of the target species as well as their strength (e.g. push or ram through fencing) need to be considered. These species characteristics influence fence height, the type of fencing material (e.g. mesh-wire, chain-link, electric), the type of post (wood, metal, concrete), the strength of the material, as well as specific features to discourage climbing (e.g. outriggers) or digging (dig barrier).

The wildlife fencing along the SP-225 appears to not have been designed with specific wildlife species in mind. It is essentially a livestock fence (similar height as a livestock fence) with chain-link attached to the posts instead of barbed wire (Figure 16), though this design has not been consistently implemented (Figure 17). Since capybara (*Hydrochoerus hydrochaeris*) is one of the most commonly hit large mammal species in this region, capybara can be expected to be one of the target species. However, capybara may require 1.80 m high fencing; much higher than standard livestock fencing.

Figure 16: "Wildlife" fence that is basically a livestock fence with chain-link attached to the lower portions of the fence posts, along SP-225, near Brotas, São Paulo, Brazil.

Figure 17: Inconsistent wildlife fencing with a more permeable fence closer to a multifunctional structure (there is a bridge across a river a few hundred meters further on the right), along SP-225, near Brotas, São Paulo, Brazil.

During the installation of wildlife fencing care should be taken not to leave gaps between the ground and the bottom of the fence (Figure 18), and, dependent on the target species and their climbing abilities, a wildlife fence should typically maintain a certain minimum distance from trees and shrubs, including overhanging branches. Constructing a wildlife fence away from shrubs and trees also reduces fence maintenance (e.g. no fallen branches or trees that can damage the fence), and it allows for easy access to repair the fence in case damage – regardless of the cause - has occurred. On the other hand a fence that is positioned close to shrubs or trees may not impact landscape aesthetics as much as a fence that is positioned further away from shrubs and trees.

Figure 18: If medium mammal species are among the target species, care should be taken that the design of the wildlife fence does not result in gaps. In this case a concrete gutter for drainage goes under the wildlife fence and leaves a gap where medium mammal species can crawl under the fence and access the fenced road corridor, along SP-225, near Brotas, São Paulo, Brazil.

The integrity of a wildlife fence can be affected by abiotic and biotic factors. Abiotic factors can include time affecting the material (e.g. crumbling of concrete (Figure 19) or rust) and physical impacts (e.g. erosion etc.). Biotic factors can include wildlife species and humans creating gaps under or in the fence (Figure 20-23).

Figure 19: Disintegrated fence posts of a "wildlife fence" overgrown with vines (i.e. this is essentially a livestock fence with chain-link attached to the lower portions of the fence posts), along SP-225, near Brotas, São Paulo, Brazil.

Figure 20: An animal (likely a nine-banded armadillo (*Dasypus novemcinctus*)), has dug under the fence and made its burrow on the road side of the fence in the fenced road corridor.

Figure 21: Damaged "wildlife fence" (i.e. this is essentially a livestock fence with chain-link attached to the lower portions of the fence posts), probably because animals have pushed down the chain-link to access the fenced road corridor, along SP-225, near Brotas, São Paulo, Brazil.

Figure 22: Damaged "wildlife fence" (i.e. this is essentially a livestock fence with chain-link attached to the lower portions of the fence posts), along SP-225, near Brotas, São Paulo, Brazil.

Figure 23: Gap in wildlife fence in median next to wildlife underpass, SP-225 motorway, São Paulo, Brazil.

4.2.2. Wildlife Crossing Structures

The purpose of safe crossing opportunities for wildlife is to:

1. Allow wildlife to safely cross to the other side of the highway.
2. Reduce intrusions by wildlife into the fenced road corridor by providing sufficient numbers of suitable safe crossing opportunities at the correct locations.

Most of the safe crossing opportunities for wildlife along the SP-225 are concrete box culverts (Figure 24) that sometimes also have a function for hydrology or livestock. The concrete box culverts are typically a few meters wide and a few meters high.

Figure 24: Wildlife underpass (concrete box culvert), along SP-225, near Brotas, São Paulo, Brazil.

It is best to construct wildlife crossing structures in such a way that it allows wildlife that approaches the road to see the sky and vegetation on the other side of the road through or across the structure. This means that the approach for wildlife should preferably be level (avoid steep slopes at the approaches (e.g. Figure 25-26)), and that two separate structures for the two travel directions should be designed as one wildlife crossing structure with a good line of sight for wildlife.

Figure 25: Wildlife underpass (concrete box culvert), along SP-225, near Brotas, São Paulo, Brazil. Note: this structure is along the "old" highway (now only one travel direction). The "new" two lanes are behind the photographer and are for traffic going in the other direction. However, the "new" roadbed is higher than the old roadbed, and the structure in the "old" highway is substantially lower than the structure under the new roadbed. This does not allow wildlife to see through both structures when they approach the highway, and it requires wildlife to descend into a dark cave (when coming from this direction).

Figure 26: Wildlife underpass (concrete box culvert) that is not visible to wildlife until they are really close to it, along SP-225, near Brotas, São Paulo, Brazil.

The decision process on where to locate safe crossing opportunities for wildlife should ideally include land use planning to ensure that good wildlife habitat continues to be present leading up to the structures. Otherwise one may run the risk that the habitat, specifically cover, leading up to the structures is destroyed and that the wildlife use of the structure is reduced (Figures 27-29).

Figure 27: Freshly cut eucalyptus plantation next to a wildlife underpass, SP-225, near Brotas, São Paulo, Brazil.

Figure 28: Freshly cut eucalyptus plantation next to a wildlife underpass, SP-225, near Brotas, São Paulo, Brazil.

Figure 29: Freshly cut eucalyptus plantation next to a wildlife underpass, SP-225, near Brotas, São Paulo, Brazil.

4.2.3. Multifunctional Crossing Structures and Hydrology

Multifunctional crossing structures may be primarily constructed for one purpose (e.g. passage of water or livestock), but – with or without some modifications - they can also function as a safe crossing opportunity for wildlife. There is a variety of multifunctional underpass types along the SP-225 (Figures 30-31).

Ideally crossing structures for water have similar stream characteristics (substrate, water velocity etc.) inside the structure as upstream and downstream of the structure. This should allow the structure to function as a crossing structure for aquatic species. If semi-aquatic and terrestrial habitat is provided for, the potential for wildlife use increases further. Note that medium and large sized mammals may require underpasses that are about 7-10 m wide and 3-5 m high.

Figure 30: Culvert for hydrology that is also used by wildlife (including capybara), along SP-225 motorway, near Brotas, São Paulo, Brazil. Note that it would be better to have a "bottomless" culvert or bridge to mimic the stream characteristics upstream and downstream of the structure. Furthermore, it would be better if semi-aquatic and terrestrial habitat would also be provided for inside the structure.

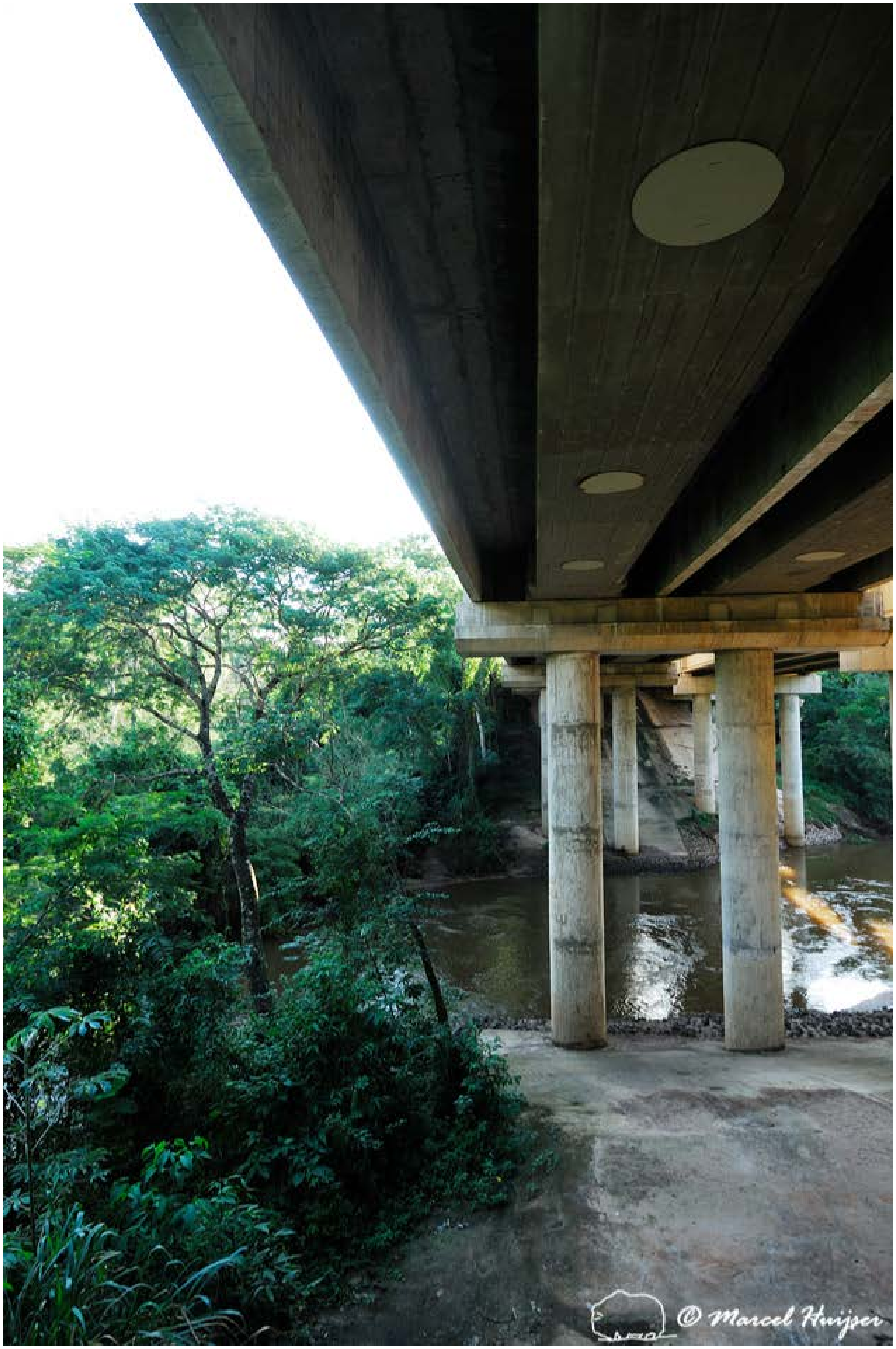

Figure 31: Multifunctional underpass (bridge) along Rio Jacaré-Pepira, SP-225 motorway, Brotas, São Paulo, Brazil. Note that it would be better to have natural surface (soil, rocks) and vegetation under the structure instead of smooth concrete.

Regardless of any modifications to a structure, the wildlife fencing needs to connect to a multifunctional underpass to allow wildlife to access the structure. However, in some cases along the SP-225, the wildlife fencing bypasses culverts intended for hydrology (Figure 32), essentially preventing wildlife from accessing the culverts.

Figure 32: Culverts for hydrology that are inside the fenced road corridor, SP-225, near Brotas, São Paulo. If wildlife fencing is tied into the structure, the culverts can also be used by wildlife. Currently the wildlife fencing prevents wildlife from accessing the culverts. Note that it would be better for wildlife to have one large structure rather than two separate parallel culverts.

Run-off from the road (and associated pollutants and sediments) should – in general - not directly flow into streams or rivers. It is best to allow the water to filtrate into the soil, reducing peak flows and the probability of flooding downstream. In addition, the soil can help filter out potential pollutants and sediments before the water enters a steam or river. Basins in the right-of-way (see Figure 33) are a measure that allows for such practices.

Figure 33: Basin to reduce the velocity and quantity of water and allow infiltration and associated removal of sediments and potential pollutants in the soil rather than a stream, along SP-225 motorway, São Paulo, Brazil

4.3. Suggestions for Wildlife Fences, Wildlife Crossing structures, Multifunctional Crossing Structures and Hydrology

Suggestions for wildlife fences (Based on Huijser & Ferraz, 2015):

1. Do not implement wildlife fencing without also providing for safe crossing opportunities for wildlife.
2. Before designing a wildlife fence decide on the “target species”.
3. Base the design of wildlife fence on the biological characteristics of the target species.
4. Use material (fence posts, fencing material) that is consistent with the desired lifespan of the fence.
5. Oversee fence installation to make sure no gaps or other weak points in the fence result.
6. Implement fence maintenance programs, including for fallen trees and vines and other vegetation growing on and over fences, (e.g. include maintenance requirements in contracts with toll road companies). Without fence maintenance wildlife fences typically become dysfunctional quickly. Currently, most of the wildlife fencing along the SP-225 has serious design, construction and maintenance issues.
7. When implementing wildlife fencing (in combination with safe crossing opportunities for wildlife) consider implementing the fencing over several kilometers of road length rather than at shorter road sections. If wildlife crossing opportunities are included, e.g. at least

one large mammal crossing opportunity once every 2 kilometers, make the wildlife fencing connect to the wildlife structures without gaps in between.

8. Wildlife fencing should cover the road length that may have a concentration of wildlife-vehicle collisions with the target species (i.e. "hotspots") and adjacent buffer zones to keep the animals from simply crossing the highway at the fence ends. The length of the buffer zone is at least partially influenced by the home range size of the target species.
9. Always install wildlife fencing on both sides of a highway, not only on one side.
10. Always try to have wildlife fencing start and end on opposite sides of the highway rather than in a staggered pattern.
11. Consider implementing wildlife guards (similar to cattle guards) or electric mats embedded in the roadway to reduce wildlife intrusions into the fenced road corridor at fence ends and at access roads.

Suggestions for wildlife crossing structures (Based on Huijser & Ferraz, 2015):

1. Always consider implementing safe crossing opportunities for wildlife when installing wildlife fencing.
2. Wildlife crossing opportunities without (functional) wildlife fencing are likely to have fewer wildlife move through the structure, and may not reduce direct wildlife mortality as a result of collisions with vehicles.
3. Before designing safe wildlife crossing opportunities, and before deciding on the number and location of the safe crossing opportunities, decide on the "target species".
4. Built a greater variety of types of wildlife crossing structures; not only wildlife underpasses at stream crossings, but also in higher and drier areas including vegetated wildlife overpasses and canopy crossings. Of course it is important to do this with the biology of the target species in mind and at locations where it makes most sense.
5. Built a greater variety of dimensions for wildlife underpasses (e.g. include larger underpasses (e.g. about 7-10 m wide, 3-5 m high) and smaller pipes (e.g. 0.5-1.0 m in diameter). Of course it is important to do this with the biology of the target species in mind and at locations where it makes most sense.
6. When possible, allow for cover inside underpasses and on overpasses as this provides good habitat for invertebrates, amphibians, reptiles and small mammals.
7. Accompany the implementation of wildlife crossing structures with research to investigate wildlife use and learn about possible preferences of the different target species with regard to the type and dimensions of the crossing structures.
8. When duplicating a highway (i.e. making a 2-lane highway into a 4-lane highway), consider the structures for the two travel directions as one wildlife crossing structure rather than as two separate ones. This implies that the type and dimension of the crossing structures for the two travel directions should generally match, and that the structures should be at the same level allowing wildlife to see through both structures when they approach the highway.
9. Create a very gradual, preferably level, approach for wildlife when approaching wildlife crossing structures. Avoid steep slopes (uphill or downhill), allow wildlife to see the sky and vegetation through or across the structure.
10. Consider land use planning in a zone adjacent to the mitigated road corridor to ensure that wildlife habitat continues to exist close to the crossing structures.

Suggestions for multifunctional crossing structures and hydrology (Based on Huijser & Ferraz, 2015):

1. At stream and river crossings, do build structures that provide space for aquatic, semi-aquatic and terrestrial species. Note that this also reduces the risks for failed structures and failed roadbeds during periods with high precipitation.
2. It is important to not only built wildlife crossing opportunities in low and wet areas. Also build wildlife crossing structures in high and dry habitat as different wildlife species have different habitat preferences. Of course it is important to do this with the biology of the target species in mind and at locations where it makes most sense.
3. Allow for a natural streambed and natural stream dynamics when possible (i.e. bridges or bottomless culverts).
4. Avoid dividing walls or pillars inside a structure; make it as open as possible (one structure rather than multiple parallel structures) to allow wildlife to see the sky and vegetation on the other side of the structure.
5. Do not allow run-off from the road and right-of-way to directly enter streams or rivers. Direct run-off from the road and right-of-way to basins. This reduces peak flows and the likelihood of flooding downstream. In addition, the soil can filter out the pollutants and sediments before they enter the stream.
6. Culverts or bridges originally designed for water (e.g. or livestock) that lack (functional) wildlife fencing are likely to have fewer wildlife move through the structure.

5. REFERENCES

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